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On New Forms of Levels. By H. H. Turner, M.A., B.Sc.

The striding or hanging level in its usual form has so often given erroneous results that it is perhaps unnecessary to quote instances in detail. The errors chiefly arise from want of uniformity in the scale; and it is no doubt a serious difficulty to obtain a tube of glass of sufficiently slight and sufficiently uniform curvature to make the scale even approximately the same in different portions of its length. Moreover, the usual method of dealing with an erroneous scale—careful determination of the division errors by calibration—is not here completely applicable; for the length of the bubble changes with temperature, and the division errors for one temperature are not the same as for another. Experiments made in 1889 on some level bubbles used in the determination of the Paris-Greenwich longitude showed that this effect of changes of temperature was perhaps not so great as might be expected, and that a table might be formed at a mean temperature for correcting the mean of the readings of the ends of the bubble, which would apply without serious errors at all moderate temperatures. But this process cannot be called satisfactory when great accuracy is desired.

It occurred to me recently that we could be independent of this unsatisfactory scale if the small screw for adjustment of zero of the bubble were made a fine micrometer screw. This screw would then be turned until the bubble took up a definite position on the scale, and the micrometer head read; on reversing the bubble the screw would again be turned until the same position was reached, and the head again read. The difference of readings of the screw is then twice the level error, and the scale is no longer used except as a series of fiducial marks, any one of which may be selected according to convenience. Messrs. Troughton & Simms readily undertook to make an experimental level-bubble on this plan, and the only practical difficulty they encountered was in providing a fine enough screw. They ultimately decided to obtain the requisite sensitiveness by making the screw act on a system of levers instead of one lever only. A striding-level with micrometer screw was received from them on 1891 July 7, and found to work satisfactorily. Three others were therefore made for use with the portable transits in the proposed Montreal-Greenwich longitude operations, which it was hoped to commence this year, but which were finally deferred until 1892. The use of these levels in the meantime with one or other of the portable transits * has suggested the following remarks:—

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* The Transit Circle object-glass was removed by Messrs. Troughton & Simms for repolishing on 1891 August 10, and the transits were in constant use for time determination at the Royal Observatory from that date until October 5.

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I. The addition of the screw does not, of course, diminish but increases the time required for an observation of level and the probable error of a single observation, for there are now two things to observe instead of one, and two sources of error. It is the systematic and not the accidental errors that are diminished. In practice, I think, it will be found best to make each observation of level consist of four distinct operations, somewhat as follows :—

Reading of Screw.	Direction of Motion.	Readings of Bubble.	
		E.	W.
r		d	d
9·500	Incr.	15·2	69·6
9·500	Decr.	15·6	69·9
10·000	Incr.	69·0	14·7
10·130	Decr.	71·2	17·0

The first pair of readings is taken without disturbing the instrument, except to turn the screw head in opposite directions to the reading 9·500. The slight difference of readings of the bubble will be referred to presently (IV.). The level is then reversed and another pair taken. To avoid holding the screw too long with the fingers, and thus possibly warming one end of the level, it is set quickly to a reading estimated to be approximately that which will bring the bubble to its old position; and the error of this estimation, which becomes obvious on taking the readings of the bubble, is corrected in the second setting of the screw by arranging that the mean of the second pair of bubble readings shall be nearly the same as the mean of the first pair. If the relation between the value of a revolution of the screw and that of one division of the scale is even approximately known, this coincidence of the mean readings can be readily secured with considerable accuracy. The present example was chosen as a rather unfavourable instance, the difference of the means ($42^{\mathrm{d}}{\cdot}98$ and $42^{\mathrm{d}}{\cdot}58$) being $0^{\mathrm{d}}{\cdot}4$, and for this a correction must be applied, depending on the value of the bubble-scale; but it is obvious that no sensible error in level will be introduced by a moderately erroneous scale value for such a small quantity.

II. The additional labour during the operations is to some extent compensated by a saving in preliminary determination of constants. The evaluation of the screw is much less laborious than the calibration of the scale, for the want of uniformity in different parts is much smaller, and, in fact, should be insensible if the screw is properly made by a good maker; whereas no one has yet apparently succeeded in making uniform bubble-scales. Moreover, the evaluation of some screw, viz. that of the level-prover, is also necessary for the ordinary form of level-bubble; and consequently the requisite labour is to some extent common to both cases. The new form of level is, in fact, simply a combination of level and prover in one instrument.

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III. It may be remarked that there is a definite advantage gained in the possibility of selecting the part of the scale to be used. Not only can certain accidental errors be eliminated by using different parts of the scale at different times during the observations, but the more defective parts of the scale may be avoided. Such are either:—

(*a*) Parts where the value of a division changes most rapidly. If the scale of an ordinary level be calibrated, and the value of one division at different parts of the scale be plotted on paper in the ordinary way, the resulting curve generally has one or more points of inflexion. At these points the rate of change in the value of one division is a maximum, and the accidental error of an observation is therefore large. A rough calibration of the scale for the detection of such points is therefore advisable even when the micrometer screw is added, so that readings of the bubble at such points may be avoided; and on the other hand, of course, the best points to select for readings should be chosen, which are those where the curve indicates a uniform scale.

(*b*) Parts where there is something in the nature of a frictional obstruction in the glass. Without further comment I may perhaps refer to a note by Mr. G. C. Comstock in the *Sidereal Messenger* for 1891 June, p. 299. Referring to a remark of Prof. Safford's, that "In some cases impurities in the ether dissolve particles of the glass, loosen other particles, and make the bubble sluggish by adhesion," Mr. Comstock continues: "It is interesting to note that this peculiarity of levels has been made the subject of special study by one of the scientific bureaux of the German Government," and gives the following account of the results attained:—

"In the course of time secretions are formed upon the inner surface of the glass and render the level unfit for use. It has been ascertained by experiment that these are due to the action of the water, traces of which are usually found in the ether with which the levels are filled. Since it is exceedingly difficult to fill a level with ether which is entirely free from water, a kind of glass which is but little affected by the action of water should be chosen in the construction of the level. A method for testing this quality of the glass by means of a colour reaction has been devised, and may easily be applied even by an unskilled person. Let a glass tube be filled with a solution of water and ether containing also a little eosin. After the solution has stood for some time in the tube the glass will assume a ruddy tint, and the greater the action of the water upon the glass the more pronounced will this tint become. By the decomposition of the glass a certain quantity of alkali is liberated and is transformed by the eosin into a coloured salt.

"The conclusion of the whole matter reached by the author of the report is, that a level tube before it is filled should always be subjected to a special treatment, consisting in removing from

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the ground-glass surfaces their alkaline components by means of an acid."

IV. It may be questioned whether a certain amount of sluggishness is not discernible in all bubbles. In a sensitive level the bubble approaches the position of equilibrium gradually, and may take several minutes of time to reach it. Readings taken before the end of this time will be in excess or defect according as the bubble is moving in the negative or positive direction. The screw provides a means of giving a gentle motion in opposite directions, and thus sensibly eliminating any errors which may be introduced by the necessity for reading without wasting too much time. An example was given in remark I., and is fairly representative, the difference of $0^{d}\cdot35$ between the readings of the bubble when brought to the same reading ($9^{d}\cdot500$) of the screw, but in opposite directions, being about the mean of such observed differences for the four levels used at Greenwich. Of course with the ordinary form of level such a motion may be given by a gentle tilt with the hand, though this is more liable to be jerky; and it is to be feared that the tendency is rather to set the level down indifferently and trust to the errors balancing in the long run, though it is quite conceivable that a habit might be acquired of setting down one end always first, in which case a systematic error would be introduced.

V. Level bubbles are sometimes permanently attached to instruments (as in the altazimuth used at the Royal Observatory, Greenwich), and are only reversed in the reversal of the instrument. In such cases, changes of temperature are apt to alter the zero of the bubbles so that they run off the scale for some positions of the instrument, unless the adjusting screws are altered to correspond. The addition of a micrometer screw to such levels would not indeed remove the necessity for altering the adjusting screw, but would rather make it a necessary part of every observation, so that the alteration would not be unexpectedly found necessary at an inconvenient time, as is sometimes the case at present when bad weather has interrupted the observations for some time.

The announcement of the above paper suggested a new form of level to Dr. A. A. Common, which he has asked me to describe briefly in an additional note. He proposes to combine some of the advantages of the nadir-observation and the striding-level determination and avoid some of their disadvantages, in a new instrument which can be readily placed on the pivots in various positions of the latter, reversed end for end, or removed, just as the striding-level, and the fundamental principle of which shall be reflexion from mercury as in the nadir-observation, instead of the motion of an air-bubble. The cylindrical tube joining the uprights of this instrument is a telescope tube, a flat bar being added above or below the tube to ensure rigidity. To the object-glass is firmly attached a reflecting prism, and the

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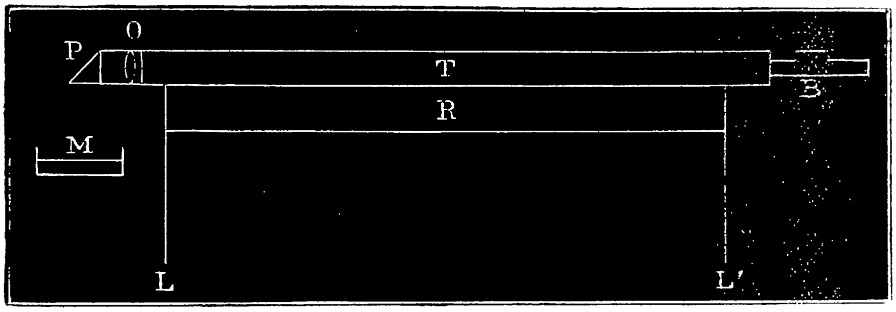
eyepiece is a Bohnenberger, with wire frame. The light from the wires passes through the object-glass and is reflected vertically downwards by the prism to a trough of mercury placed underneath the projecting face of the prism, is returned to this face of the prism and back through the telescope, forming an image of the wires in the same plane as themselves. A micrometer screw applied either to the whole telescope and prism, or to the wires alone, will give a reading for coincidence, the difference of which, from a similar reading for coincidence in the reversed position of the instrument, will be twice the level error. No instrument of this kind has yet been constructed, and it may be found necessary to modify the details; but the principle is in some ways new, and it was thought advisable to include this brief sketch of the idea in the present paper. A diagrammatic section of the proposed instrument would be somewhat as below.



B = Bohnenberger eyepiece. The illumination of the wires may be effected by the axis-lamp of the transit by an additional prism to throw this light upwards towards the reflector in B.
O = object-glass of telescope T.
P = reflecting prism.
M = Mercury trough.
L, L′ = legs to stand on pivots, as in the striding-level.
R = flat bar to strengthen the connections.